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A Diachronic Analysis of a Changing Landscape on the Duero River Borderlands of Spain and Portugal Combining Remote Sensing and Ethnographic Approaches

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Abstract: The Arribes del Duero region spans the border of both Spain and Portugal along the Duero River. On both sides of the border, the region boasts unique human-influenced ecosystems. The borderland landscape is dotted with numerous villages that have a history of maintaining and managing an agrosilvopastoral use of the land. Unfortunately, the region in recent decades has suffered from massive outmigration, resulting in significant rural abandonment. Consequently, the once-maintained landscape is evolving into a more homogenous vegetative one, resulting in a greater propensity for wildfires. This study utilizes an interdisciplinary, integrated approach of "bottom up" ethnography and "top down" remote sensing data from Landsat imagery, to characterize and document the diachronic vegetative changes on the landscape, as they are perceived by stakeholders and satellite spectral analysis. In both countries, stakeholders perceived the current changes and threats facing the landscape. Remote sensing analysis revealed an increase in forest cover throughout the region, and more advanced, drastic change on the Spanish side of the study area marked by wildfire and a rapidly declining population. Understanding the evolution and history of this rural landscape can provide more effective management and its sustainability.

Keywords: rural abandonment; temporal land cover change; remote sensing; ethnographic landscape perceptions

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1. Introduction

Since the mid-20th century, a demographic shift from rural to urban society has occurred in much of the world [1,2]. In the European Union, Spain and Portugal are among the most affected in this demographic shift, in terms of rural agricultural land abandonment. According to the European Commission, by 2030 Spain is expected to lose the highest level of agricultural land due to land abandonment in the European Union, at over 1 million hectares. Portugal, despite its smaller percentage of arable land, is expected to be three percent above the EU average of land abandonment [3]. Worldwide, causes of rural land abandonment vary among demographic [4], political [5], socioeconomic, and ecological shifts [6,7]. Although rural abandonment has undoubtedly led to more wild vegetative growth, in some regions it has had positive effects as a means of carbon sequestration, the improvement of water quality, or the prevention of soil erosion [8,9]. For the Mediterranean region, however, it has often led a decrease in biodiversity [10].

The biodiversity found in Mediterranean ecosystems evolved as a result of the historical development of a "mosaic" of habitats created by human agrosilvopastoral use of the landscape [11,12]. Rural abandonment has contributed to a loss of biodiversity and habitats, but the consequent increase in vegetative growth [13,14] has also been a significant cause of wildfire, particularly in southern Europe [15,16].

Recognizing the demographic decline of rural agropastoral economies and communities, governments have looked to strategies to mitigate the ecological and socioeconomic effects of these changes [17]. Focusing on both the rural and the ecological characteristics of these regions, natural parks and biosphere reserves have been created in order to readjust the ecosystem services of the landscapes from ones based on provisioning (food production, fuel, and water) to another favoring support services, represented by ecological protection and the promotion of rural tourism [18,19]. Although perhaps introducing a new source of regional income through ecological and cultural tourism from natural park creation, the policy of preserving forest resources has only exacerbated the increase in vegetative growth initially caused by land abandonment and puts into question the idea of landscape sustainability defined by Wu as the "capacity of a landscape to consistently provide long-term, landscape specific ecosystem services essential for maintaining and improving human well-being" [20]. These preservation policies have had social consequences as well. Residents, accustomed to traditional land use, often struggle to make these adjustments from the more top-down decisions, often resulting in resentment and even conflict [5,21–24].

The loss of rural landscapes throughout the world and particularly in Europe has both ecological and cultural implications. Policies to prevent this loss, and approaches to analyze it, require strategies that recognize the synergy of the ecological and cultural aspects of landscape. An interdisciplinary "toolbox", implementing methods from archaeology, ethnography, and the environmental sciences, is essential to monitor the land cover diachronic changes in rural landscapes that have become more intensified in the last 60 years [25,26]. Monitoring land cover over time has been accomplished using a plethora of tools, from the incorporation of georeferenced historic maps [25], multi-source spatial data [27], and satellite image analysis [28–30], plus the combination of socioeconomic data with satellite image analysis [31]. Documenting temporal regional changes using a variety of sources will be necessary to effectively protect, manage, and plan for the future of these rapidly changing landscapes.

Building on previous interdisciplinary archaeological/historical landscape studies conducted in the region [32–35], this research adds to the diachronic analyses of the anthropic influence on this landscape. This study aims to demonstrate the land cover changes that have occurred as a result of socioeconomic factors and human decisions since the early 1980s to the present day. It will detail this land cover evolution through the integration of three data sets: (1) Ethnographic data, (2) Remote sensing spectral analysis, and (3) Demographic statistical data.

2. Materials and Methods

2.1. The Study Area

The study area is composed of two parallel border regions between Portugal and Spain, expanding over an area of 56,764 hectares (Figure 1). The Duero River, forming much of the border between these two nations, forms both an ecological and cultural focal corridor. Expanding outward from the banks of this iconic river, the research area includes eight pilot case study municipalities on both sides of the border. In Portugal, they consist of four parishes in the county of Miranda do Douro: Constantim-Cicouro (3633 ha), Ifanes-Paradela (4470 ha), Miranda do Douro (3551 ha), and Vila Chã de Braciosa (4293 ha) in the south. Opposite of these parishes, to the east on the Spanish side of the Duero River, the study area consists of four Spanish municipalities: Pino del Oro (2960 ha), Villardiegua de la Ribera (2887 ha), Argañín (1265 ha), and Fariza (9044 ha).

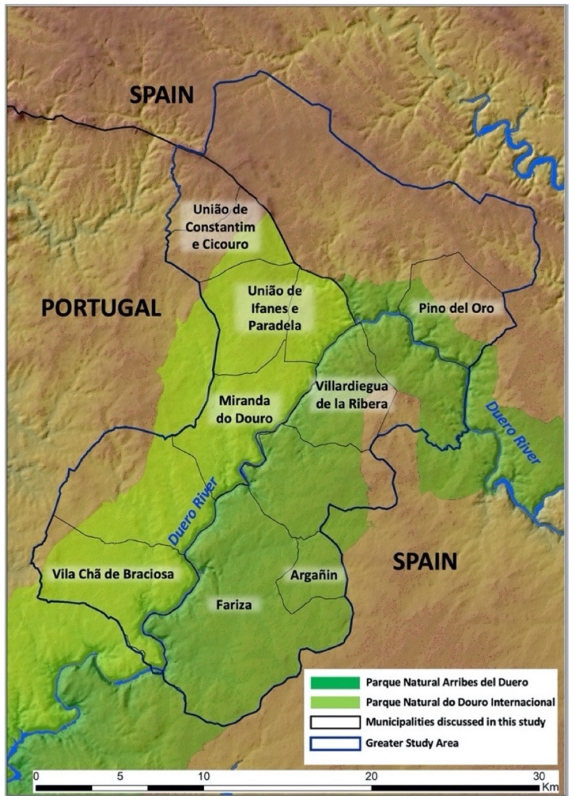

Figure 1. The internationally protected Duero River borderland region of the study area.

The region has two microclimates: a warmer, less fluctuating, Mediterranean one in the river valley, and the other, located on the high plains on both sides of the Duero River. Prone to extreme seasonal variation, the high plains region has more continental-type temperature variation [36,37]. The natural vegetation in these microclimate zones is varied as well. Within the sheltered deep river valley, several *Quercus* species can be found with *Pistacia terebinthus* and *Juniperus oxycedrus* subsp. *Badia*. These stands are mixed with scrub vegetation such as *Lavandula stoechas*, *Cytisus multifloris*, and *Daphne gnidum.* Extending out onto the plains away from the river both *Quercus ilex* and *Quercus pyrenaica* become the more dominant arboreal wild species [36,37]. Mixed with cereal crop agriculture on the plains are other scrub species such as *Cytisus scoparious*, *Genista hystrix*, and *Cistus landanifer*. In lesser alluvial systems on the plains, ash trees *Fraxinus angustifolia* interspersed with several species of willow *(Salix fragilis*, *Salix atrocinerea* and *Salix salviifolia)* can be found as well.

Over the centuries, humanity has significantly altered the landscape with agrosilvopastoralism. Viticulture and various Mediterranean tree crops have become established. Cereal crops, namely rye, wheat, and barley, were planted in soils most suitable for their cultivation in the larger expanses away from the cluster settlements in each municipality. Horticulture for subsistence/domestic consumption dominated the village core and nearby surrounding plots. Intermixed with the agriculture on the larger plots extending from the village core was a system of crop rotation dating to the late Middle Ages/Early Modern period [38–40]. In municipal areas that were not apt for agriculture due to overly acidic or rocky soil quality [36], scrub and wooded vegetation was common, which in turn was used for rough grazing. On the wooded canyon cliffs descending to the Duero River, caprine rough pasturing was most prevalent. As populations stabilized and increased in these villages in the early Modern Period, the landscape was carefully managed, evolving into a sustained agrosilvopastoral one. Until the arrival of butane gas and, later, electricity in the early to mid-20th century, municipal woodlands were pruned, provided fuel for cooking and heating, and were also used as building material.

Beginning in the 1950s and 1960s, however, socioeconomic conditions began to pressure the residents of these rural regions to migrate internally or emigrate abroad to urban industrial centers [41–43]. This outmigration led to a gradual large-scale rural abandonment that has resulted in not only a significant population decrease, but also landscape change unseen in the history of the region.

By the beginning of the 21st century, governments began to recognize the ecological singularity of the Duero River landscape. This led to the creation of three protected areas; the Douro International Natural Park in Portugal in 1998, which later merged with the Arribes del Duero Natural Park, created by Spain in 2003, to form an internationally protected park zone (Figure 1). Later in 2015, after an effort by both countries, UNESCO recognized and superimposed yet another protected layer, the Meseta Iberica Biosphere Reserve, under UNESCO's Man and the Biosphere program (MAB) [44].

The Spanish and Portuguese municipalities covered in this study were chosen because they have been part of recent or ongoing landscape archaeological research conducted by the Social Structure and Territory Landscape Archaeology (EST-AP) group of the Spanish National Research Council (CSIC) that has documented human environment interaction dating back to the protohistoric period [32,34,45–48]. Additionally, the municipalities were selected because they were either completely within or possessed significant territory within the internationally protected natural park zone (Figure 1). Most importantly, they were found to be representative of the vegetative and topographic diversity found in the region incorporating land along the Duero River and on the exterior plains [36,37,49]. Since all of the case study municipalities are not contiguous, the greater study area was expanded partially beyond the political borders of the municipalities to demonstrate the extent of vegetation corridor continuity. The entire study area is completely within the limits of the much larger Meseta Iberica biosphere reserve.

2.2. Satellite Imagery

Eight Landsat scenes were downloaded as level 2A products from the Earth Explorer service of the United States Geological Survey (USGS) (Table 1). Level 2A products are obtained after the atmospheric correction of Level 1 images and are distributed in surface reflectance units, also known as Bottom of Atmosphere (BOA) reflectance, which is the optimum magnitude for multitemporal analysis. Landsat overpasses the study area in the Path 203 and Row 31. Due to the long track record, some of the scenes used were acquired by Landsat 5 Thematic Mapper (TM) (available between 1984 and 2013) and some others by its heir the Landsat 8 Operational Land Imager (OLI) (available since 2013). The use of Landsat 7 imagery was avoided due to the striping pattern caused by the SLC-off effect, which would require further pre-processing [49] and cause an additional degree of uncertainty. The selected images were cloud-free scenes acquired in mid-summer (mostly in August), a period when the difference between (rainfed) agropastoral lands and natural vegetation is expected to be enhanced. With the exception of the 1984 to 1988 span, the time increment between captures was completed in five-year periods. The 1984 year was chosen as the first available year for Landsat 5. Using Landsat 5 data from the early 1980s also allowed the analysis to complement the dramatic population decline continuing to the present day. The analysis focused on visible (RGB), near infrared (NIR) and shortwave infrared (SWIR) spectral bands, with a spatial resolution (pixel size) of 30 m.

Table 1. Landsat scenes used in the study.

Sensor	Date	Scene Cloud Cover (%)
Landsat 8 OLI	14 August 2018	0
	31 July 2013	0
Landsat 5 TM	2 August 2008	0
	5 August 2003	5
	23 August 1998	1
	9 August 1993	0
	27 August 1988	5
	1 September 1984	9

2.3. Landscape Analysis: Methodology

2.3.1. Ethnographic Perception Studies

As part of the integrated approach to diachronic landscape history and evolution of this study, this landscape change analysis incorporates an ethnographic, soft landscape perception study that details the landscape history and change within human memory from a bottom-up perspective. Landscape perception studies involve determining stakeholders' knowledge, awareness, and values attributed to a landscape [50,51].

Throughout 2017 and 2018, perception studies were conducted through a combination of personal interviews with informants and participant observation. To better interpret the perceptions of the landscape from many perspectives and to assure the saturation of results, informants from the four Portuguese municipalities and the four Spanish municipalities of the study area were interviewed. Forty-nine respondents in total participated. To maintain a diversity of opinion in the perceptions, a composite of different stakeholders were identified in their relationship to the landscape in the region.

All interviews were semi-structured ethnographic interviews. All informants gave their informed consent before they participated in the study. The style of interviewing was open-ended, with volunteer samples in all cases. The interviews were approximately between 20 min to 2 h and took place in a public setting or in the interviewee's home. The questions for local inhabitants during these interviews sought to ascertain their connection with the landscape. Additionally, question themes related to their opinion of the cultural and natural resource management of the region. Government officials were interviewed from various levels. The question themes dealt largely with issues regarding the current state of management of park lands, the enforcement of park environmental regulations, and the importance, recognition, and maintenance of both immaterial and material cultural resources found in the park lands [35]. A chain (snowball) sampling method was employed to confirm information and allow for a saturation of results [52,53]. After the interviews, recordings were transcribed and then coded for themes using the grounded theory approach. From the transcripts, informants' responses to questions were categorized forming themes of this iterative process [54–56].

2.3.2. Selection of Stable Samples

Detecting land cover change through time might be approached with different methodologies [57]. In this study, Post-Classification Comparison (PCC) [58–60] was implemented to evaluate change by comparing land cover maps obtained with supervised classification in the individual years of the study period. With this aim, a set of reference data was built for classification training and validation, which could be used consistently in the different years of the analysis. Following similar studies [61], land samples that were diachronically consistent were used, i.e., areas that remained stable during the whole study period. Using stable samples is an efficient option for studies such as this, which are based on archived satellite imagery [62].

For this reason, available aerial photography from different time periods was used to delineate different samples representative of the main landscape types. Using aerial photography or very high resolution (VHR) satellite imagery for delineating ground reference samples is a common practice in land cover analyses [61,63]. A series of aerial photography ranging from 1946 to the present were used for digitization (see supplementary data, List S1). Even if aerial photographs are of greater detail than the input imagery used for the classification (Landsat data), reference samples digitized from them are subject to interpreter errors [64] and are difficult to quantify. For this reason, three additional sources of information were used to complement aerial photographs and improve the definition of representative reference samples: (1) field visits, (2) a vector file with the boundaries of the wildfires that have occurred since 2001 (prior to this, wildfire occurrence data was only available for Spain from 1989 to 1999 in the study area, at 335 total hectares burnt), and (3) historical municipal level maps (planimetries) of the late 19th to early 20th century for Spain. Although the latter did not offer the accuracy of an aerial photo or satellite image, they do identify landscape vegetative areas, using a specific nomenclature (Figure 2).

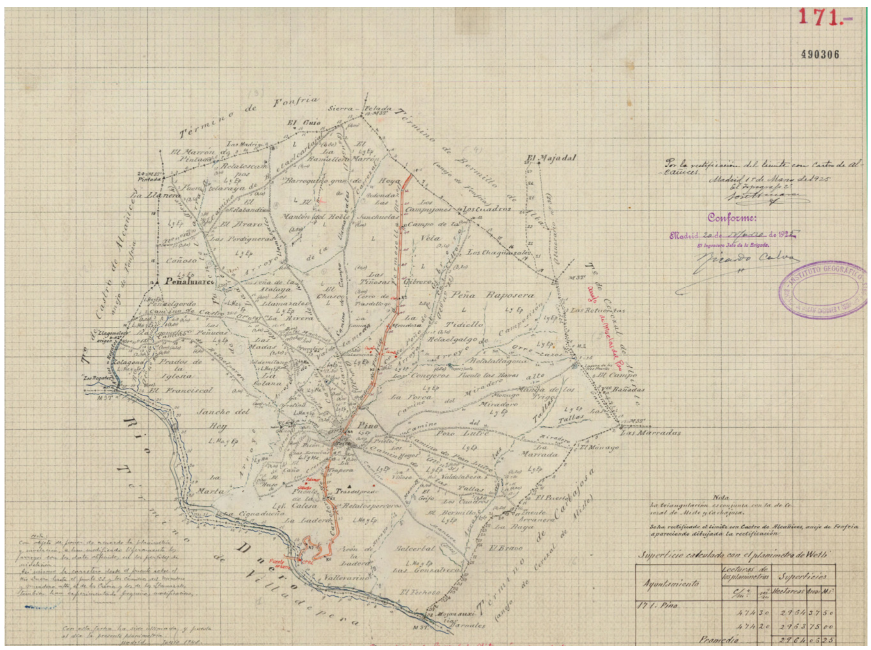

Figure 2. Planimetry map of Pino (del Oro) municipality detailing land cover types from 1907. Permission: Obra derivada de PACON 1870-1977 CC-BY 4.0 ign.es [65].

While the diversity of landscape units within the international park zone is well documented [36,37], the past anthropic influence marked by intensive use on the landscape was narrowed to demonstrate the vegetative change from agrosilvopastoral use to transition scrubland and forest cover. This study is focused on detecting the change, impact, and consequences of agrosilvopastoral abandonment and subsequent landscape policy decisions in the region. Narrowing the land cover classes to reflect the traditional land use allowed for greater precision in the subsequent classification analyses and avoided an excessive complexity in the legend that would complicate the interpretation of results. The selected classes were:

1. Agropastoral lands, where a system of annual, biennial, or triennial crop rotation allowed for the cultivation of cereal crops followed by periods of fallow, whereby ovine or bovine grazing was allowed in the same areas. In other cases, where the soil quality was poor for cultivation, the lands were dominated by grazing only with occasional plots for agriculture (Figure 3a,b);

2. Chaparral forest, dominated by *Quercus* (*ilex* and *pyrenaica*) and *Juniperus* species. Originally limited to the ravines and hilltops of the municipal common lands along the course of the Duero, they can now be seen, with aerial photography over a span of 70 years, expanding on the plain's interior from the Duero. Rough grazing is known to occur in these areas (Figure 3c);
3. Scrubland, areas of occasional *Quercus* species, but dominated by shrubland vegetation such as *Lavandula stoechas*, *Cytisus multiflorus*, *Retama sphaerocarpa*, and *Daphne gnidium*. It can be found along the upper banks of major and minor riparian systems and on the interior plains. Similar to the chaparral forest class, some rough grazing is known to occur in these areas as well. (Figure 3d);
4. Water surfaces and fluvial systems with minor systems having confluence into the primary river of the landscape, the Duero River.

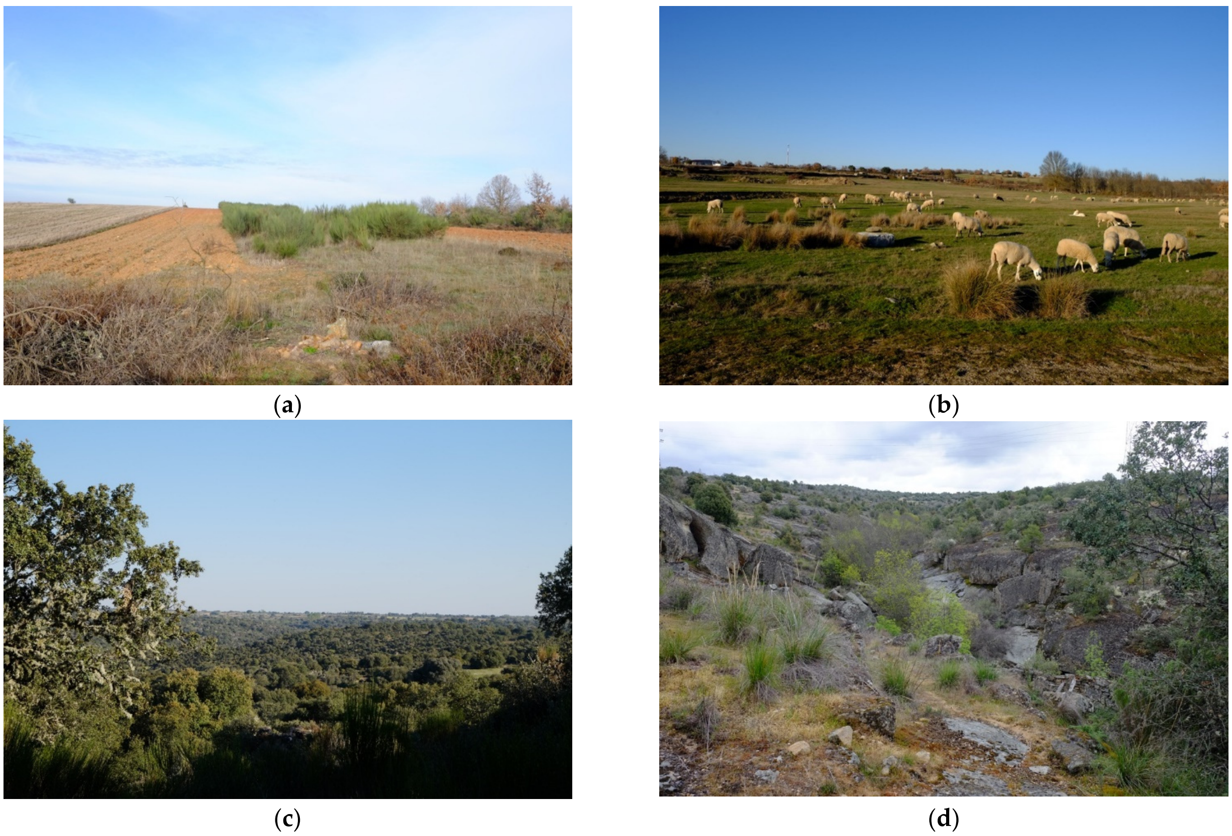

Figure 3. Photographs depicting the main land cover classes in the study site: (**a**) agropastoral land (agricultural plot), (**b**) agropastoral land (pasture), (**c**) chaparral forest, and (**d**) scrubland. No photograph is provided for water.

Stable samples were drawn as polygons delineating the four classes of representative areas as they were found on the landscape, consistently unaltered in the whole aerial photograph time series. It was assured that samples were spatially distributed throughout the study area to capture landscape heterogeneity [61] (Figure 4). The delineated land area for the different classes was kept close to 200 ha for each land cover class, to have balanced samples for the subsequent analyses (Table 2). Considering the total area of the study site, the reference samples accounted for a proportion of 1.47%.

Table 2. Summary of the stable temporally consistent sample polygons delineated for each class.

	Class	No. of Polygons	Total Area (ha)	No. of Pixels
1	Agropastoral lands	11	214	2385
2	Scrubland	29	193	2145
3	Chaparral forests	20	232	2578
4	Water	44	198	2198

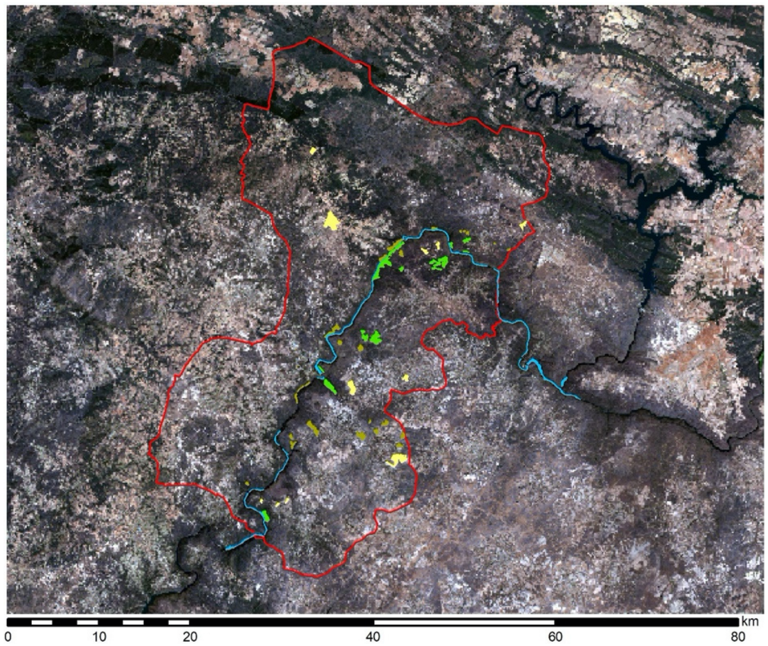

Figure 4. Study area (in red) with diachronically consistent training samples over Landsat 8 real color composite image 2013. Polygon colors are as follows, yellow: agropastoral lands, olive: scrublands, green: chaparral forests, and blue: water.

Since the spectral bandwidth and pre-processing of Landsat 5 and Landsat 8 sensors are not exactly the same, the scenes need to be adjusted [66] to ensure the consistency of the time series and a reliable multitemporal analysis. Furthermore, since the scenes acquisition dates (day of the year) differed slightly (Table 3), and the actual meteorology of each year might also slightly differ, a linear cross-calibration approach was determined as the most appropriate approach to match the scenes' radiometry and to make them comparable [67]. Using the set of stable samples, a band correlation analysis was carried out with all the scenes in the time series. The Pearson correlation coefficient (R) was computed for each scene pair on each band. The scene that achieved the highest overall R was selected as a reference. This resulted in being the Landsat 5 TM scene acquired in 1998 (Table 1). Using this reference, the remaining scenes were corrected with a linear equation that matched them to the 1998 scene. Although the resulting corrections were minor, this process ensured a precise match between the radiometry of the different scenes, which is necessary for the subsequent multitemporal analyses.

Table 3. Cross-correlation matrix. Values in the matrix indicate the mean Pearson correlation coefficient (R) between the spectral bands of each scene pair. The last column gives the mean R, used to select the 1998 scene that maximizes it. Colors illustrate different correlation values.

	1984	1988	1993	1998	2003	2008	2013	2018	Mean
1984		0.970	0.945	0.965	0.959	0.917	0.948	0.956	0.951
1988	0.970		0.943	0.971	0.957	0.940	0.959	0.965	0.958
1993	0.945	0.943		0.937	0.970	0.879	0.932	0.921	0.932
1998	0.965	0.971	0.937		0.969	0.940	0.966	0.980	0.961
2003	0.959	0.957	0.970	0.969		0.924	0.972	0.960	0.959
2008	0.917	0.940	0.879	0.940	0.924		0.931	0.946	0.925
2013	0.948	0.959	0.932	0.966	0.972	0.931		0.971	0.954
2018	0.956	0.965	0.921	0.980	0.960	0.946	0.971		0.957

2.3.3. Image Classification

After a preliminary analysis based on vegetation indices (see supplementary data, Table S1, Figures S1–S3), a supervised classification was performed for each scene, resulting in a temporal sequence of land cover maps [68–72]. The classification was accomplished using the Random Forests (RF) algorithm [73], commonly used in similar studies [74–76]. RF is an ensemble machine learning technique that generates a large number (n_tree = 100 trees in this study) of Decision Trees (DT) and assigns the final class as the majority voting of the individual DTs. RF outperforms previous DT-based algorithms and has become a standard in the remote sensing community [77]. Two features make RF particularly robust: (1) each DT is built upon a random subsample (bootstrap) of the training set, and (2) DTs are created by subdividing the sample set at each node according to the best splitting variable, selected among a random subset of the predictive variable set. The size (m_try) of this subset is normally (as well as in this study) taken as the square root of the total number of predictive variables. Therefore, independency is granted among the DTs forming the forest, resulting in classifiers that effectively handle predictive variables that might be poor predictors or even correlated with each other. As any supervised classification algorithm, RF requires a training set containing samples of the classes of interest. From the total number of samples available (Table 2), 5000 pixels (~50%) were randomly selected as training samples and the rest were used for accuracy analysis [78]. The four different classes were balanced in the training set to avoid class imbalance issues [79].

RF classifications were evaluated using standard accuracy metrics calculated on the external (i.e., independent) sample set kept for accuracy evaluation. As an indicator of the general performance of each classification, the Overall Accuracy (OA) was used, which is the % of correct predictions in the test dataset. Moreover, for each class the recall and precision metrics were computed, which represent the commission and omission errors, respectively. Finally, since RF algorithm was applied per pixel, the obtained land-cover maps were post-processed to reduce their eventual noisy appearance using a majority (mode) filter, using the eight nearest neighbors to the nearest cell (a window size of 3 × 3 and a replacement threshold value where half the cells have the same value and are contiguous).

The area of each of the classes over the successive years was calculated from the obtained classifications. Finally, the percent of change for each class was calculated for each of the eight municipalities and the larger study area. Changes for the classes were determined successively between the five-year increments, with the percent of change calculated and compared to the starting year of 1984.

3. Results

3.1. Initial Landscape Perception Studies: Perceptions of Current Landscape Challenges and Issues

After extensive participant observation and interviews with a cross section of the many stakeholders of the protected borderland region, two first order categories were detected, and several important themes were found to be common among all stakeholders regardless of their position with the regional or local government. The categories were: perceptions of conservation; management and protection of cultural resources; and the perceptions of conservation, management, and protection of natural resources (Table 4).

The most prevalent theme from the perception studies conducted throughout all the municipalities was the impact of the mass human exodus from the region resulting in an increase in vegetation and wildfires. Even in Miranda do Douro, which had seen an increase in population, informants expressed a collective concern for the depopulation of the region as a whole. Natural park creation, while lauded by regional and national officials, was not well received by remaining residents due to stringent restrictions on traditional land use, such as controlled burns and tree and brush provisioning reduction. With a focus on ecological preservation, national park creation played a significant role in vegetative change on the landscape. Moreover, it cemented the type of landscape use and ecosystem services preferred on the landscape, stymieing the traditional agrosilvopastoral landscape.

Table 4. Most common perceptions from all stakeholders on the Duero Borderland Region.

Perceptions of Conservation, Management, and Protection of Cultural Resources	Perceptions of Conservation, Management, and Protection of Natural Resources
Concern about the disappearance of the villages due to migration and mortality of older residents	Concern with the landscape's increased propensity for wildfires
Desire to develop more sustainable and profitable cultural and ecological tourism	Remaining residents are restricted in managing their lands by the park/biosphere laws and are fined for infractions
More concern with the loss of community solidarity, the natural landscape, and its diachronic change rather than archaeological heritage	Remaining residents are restricted in managing their lands by the park/biosphere laws and are fined for infractions
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3.2. Land Cover Changes

3.2.1. Land Cover Classification-Accuracy Analysis

Accuracy values of the supervised classification were high, considering all of the classes together with a mean overall accuracy (OA) of 95.1% (Table 5). Water and agropastoral classes with little diversity registered mean percentiles above 97%. Forest and scrubland, despite their diversity of vegetation growth, also registered in the 90th percentile. Consequently, all accuracy values were considered high enough to be reliable classifications.

Table 5. Land cover classification accuracy analysis results.

Year	OA	Agropastoral		Forest		Scrubland		Water	
		Recall	**Precision**	**Recall**	**Precision**	**Recall**	**Precision**	**Recall**	**Precision**
1984	93.3	98.3	95.3	95.1	92.1	93.6	86.6	99.6	99.3
1988	94.1	98.3	95.3	95.8	91.3	94.5	90.3	99.6	99.4
1993	93.9	98.7	96.1	95.2	90.5	94.2	89.3	99.7	99.6
1998	95.5	98.8	96.9	96.7	93.7	95.7	91.6	99.8	99.8
2003	94.6	99.2	98.4	95.4	90.3	94.8	90.1	99.7	99.4
2008	96.4	98.9	97.7	97.5	94.3	96.7	94.0	99.7	99.5
2013	96.6	98.9	97.6	95.8	91.0	94.7	90.4	100.0	100.0
2018	96.2	99.5	98.7	96.7	92.8	96.4	93.5	99.9	99.8
Mean	95.1	98.8	97.0	96.0	92.0	95.1	90.7	99.7	99.6

3.2.2. Land Cover Classification-Greater Study Area Land Cover Changes

The landcover maps classified under the categories of agropastoral, forest, scrubland, and water were quantitatively analyzed (Figure 5). Beginning in 1984, throughout the entire study area, the borderland area was dominated by scrubland at 50% and agropastoral lands at 39% (Table 6). Variations in both classes occurred, with slight spikes in 1988 in agropastoral land at 39% and with an increase to 53% in the scrubland class. Both classes, however, saw losses of 4% and 7.6% in agropastoral and scrubland classes, respectively. Forest cover, at only 9.81% in 1984, saw only increases with some slight negative fluctuation between years, while never returning to that same percentage. Most notably, by 2018, forest cover had more than doubled to 21.6% (Table 6). As expected, surface water, largely represented as the Duero River, had only negligible changes.

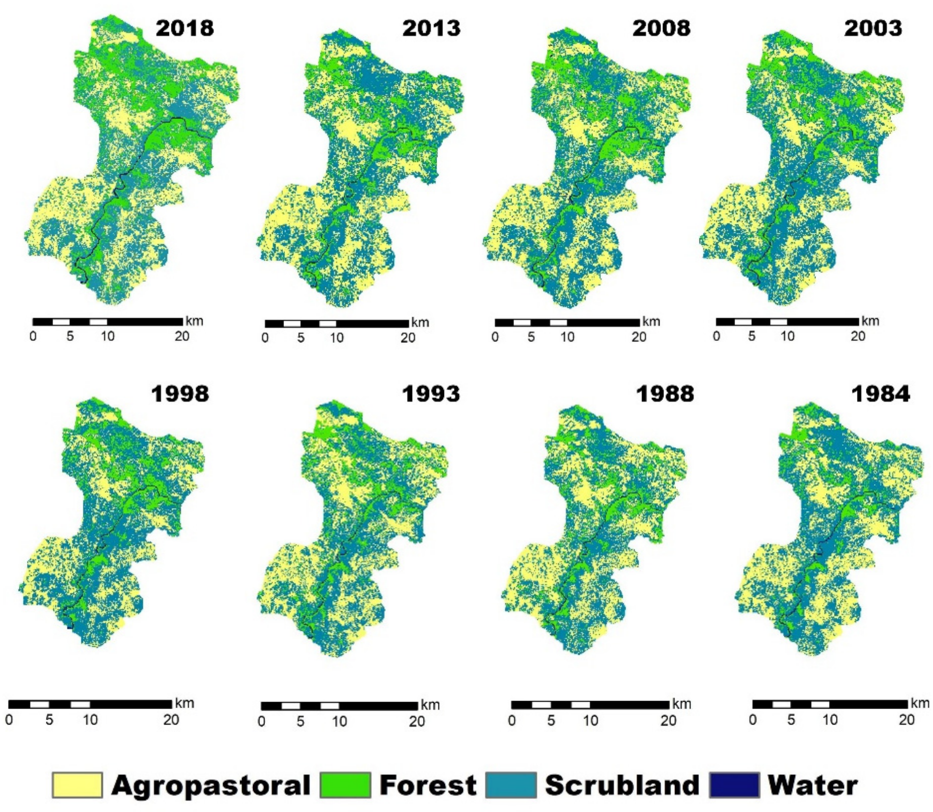


Figure 5. Land cover maps of the study area from 2018 to 1984.

Table 6. Land cover changes from 1984 to 2018, compared to starting year.

Year	Agropastoral (ha)	(%)	Change (%)	Forest (ha)	(%)	Change (%)	Scrubland (ha)	(%)	Change (%)	Water (ha)	(%)	Change (%)
1984	22,221	39.2		5566	9.8		28,455	50.1		523	0.9	
1988	22,374	39.4	0.3	8020	14.1	4.3	25,882	45.6	−4.5	489	0.9	−0.1
1993	21,815	38.4	−0.7	8758	15.4	5.6	25,737	45.3	−4.8	454	0.8	−0.1
1998	17,330	30.5	−8.6	8660	15.3	5.5	30,272	53.3	3.2	502	0.9	0.0
2003	18,765	33.1	−6.1	8711	15.4	5.5	28,768	50.7	0.5	520	0.9	0.0
2008	20,203	35.6	−3.6	9560	18.4	8.6	26,405	46.5	−3.6	597	1.1	0.1
2013	21,365	37.6	−1.5	8209	14.5	4.7	26,803	47.2	−2.9	387	0.7	−0.2
2018	19,936	35.1	−4.0	12,263	21.6	11.8	24,107	42.5	−7.7	459	0.8	−0.1

3.2.3. Land Cover Classification-Municipal Level Land Cover Changes

The general study area data provide an overview of the land cover changes occurring in the region. A more nuanced understanding of the landscape land cover change is seen, however, when the same analysis is applied to the municipalities covered in the ethnographic study. All municipal maps were extracted from the original greater study area map. As with the general study area, forest cover in all municipalities increased between 1984 and 2018 (Figures 6–9).

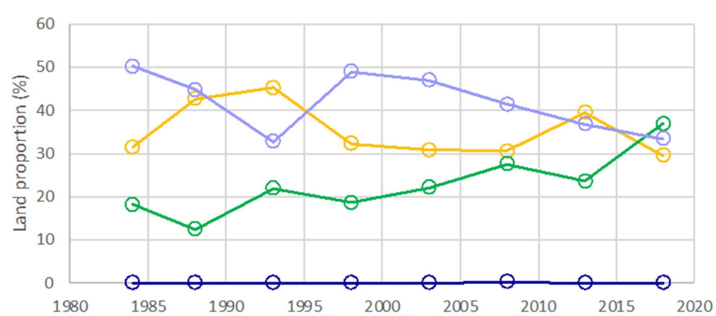
Portugal

In 1984, the Constantim-Cicouro area had a significant scrubland land cover of 50%. By 2018, after some fluctuation, it had decreased to 33%. Forest cover rose from 18% to 37% (Figure 6a).

Scrubland in Ifanes-Paradela was significant at 48% in 1984. By 2018, it had decreased to 35%. Forest cover more than doubled between 1984 and 2018, from 10% to 20% (Figure 6b).

In Miranda do Douro municipality, the agropastoral class rose from 27% in 1984 to 36% in 2018. Scrubland, beginning with a majority of land cover in 1984, at 67% of the total area, declined to 52% by 2018. Forest cover, at 4% in 1984, more than doubled to 10% by 2018 (Figure 6c).

Although less pronounced than the other Portuguese parishes, Vila Chã de Braciosa followed the same trends as the others, with a slight decrease in scrubland from 52% to 47%, between 1984 and 2018. It had an increase in forest cover from 7% to 10% of the total municipal area (Figure 6d).



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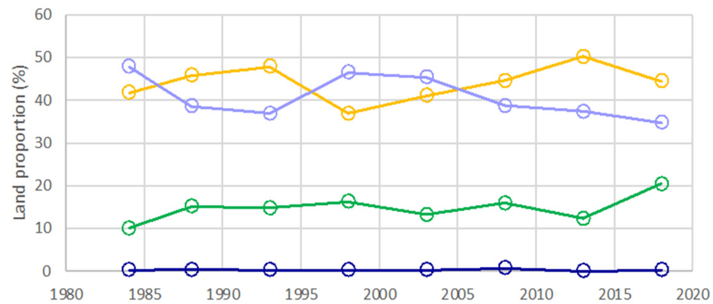

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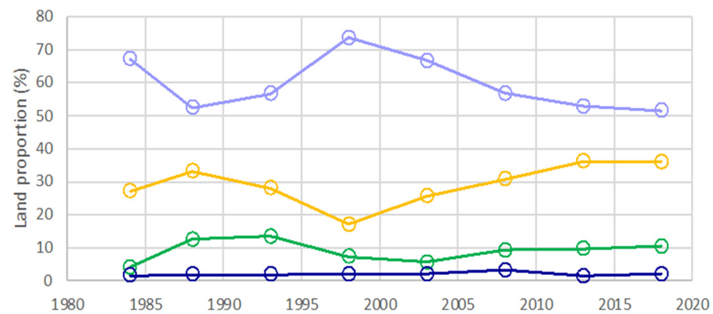

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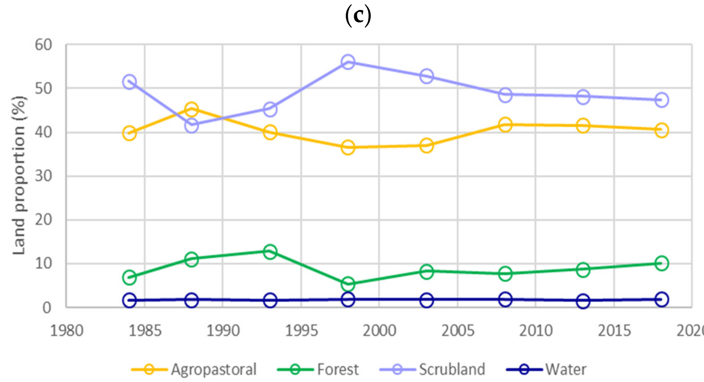


(**d**)

Figure 6. Percentage of land cover change in Portuguese municipalities: (**a**) Constantim-Cicouro, (**b**) Ifanes-Paradela, (**c**) Miranda do Douro, and (**d**) Vila Chã de Braciosa.

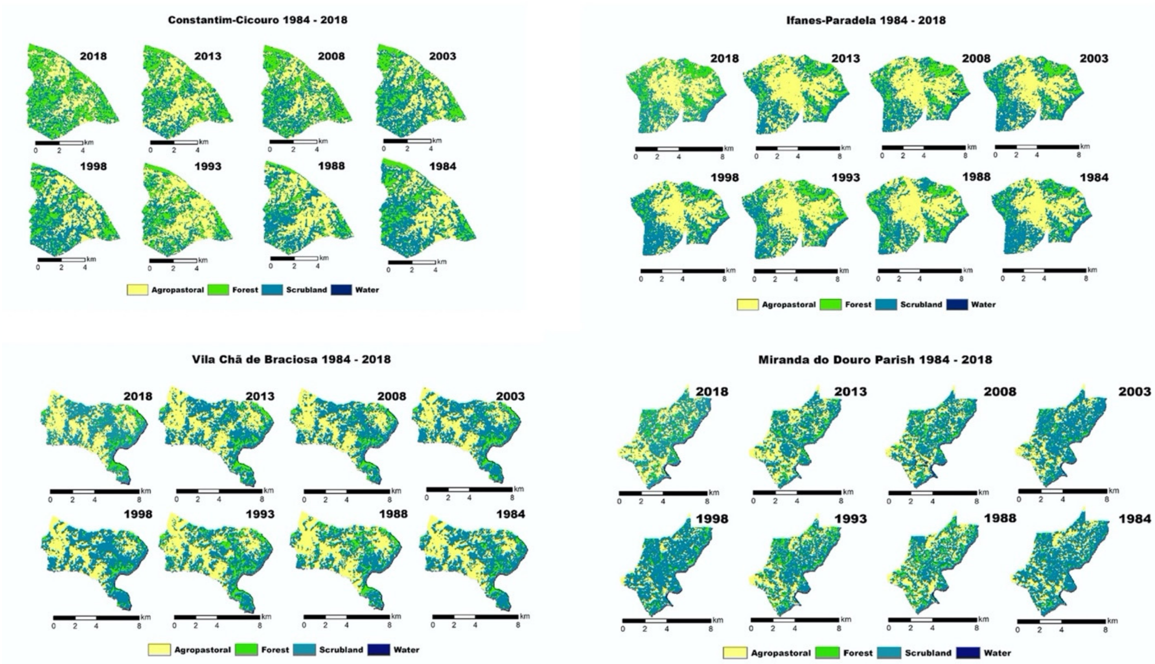


Figure 7. Temporal land cover change maps of Spanish Municipalities (1984–2018).

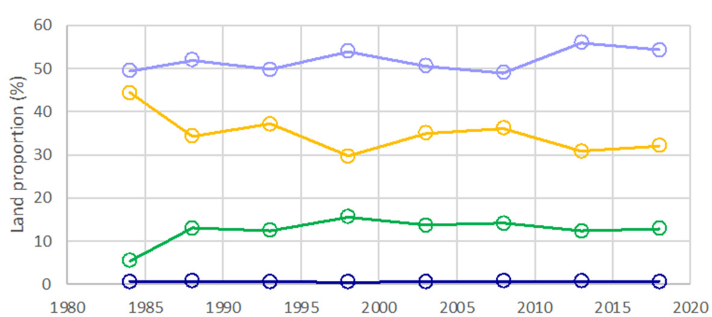
Spain

Forest cover in 1984 in Pino del Oro was at 5.45% and more than doubled to 12.92% by 2018. In 1984, agropastoral land cover was at 44.41%, yet had decreased gradually to 32.13% by 2018 (Figure 8a).

In Villardiegua de la Ribera, both the agropastoral and scrubland classes saw decreases in land cover between 1984 and 2018. The agropastoral class, beginning at 28% in 1984, decreased to 23% in 2018. Scrubland in 1984 was at 52% and decreased to 47% in 2018. Forest cover began at 18% in 1984 and increased to 27% in 2018 (Figure 8b).

Agropastoral land cover dominated the landscape of Argañín in 1984 at 64%, followed by scrubland at 36%. Forest only meagerly appeared at 0.09%. By 2018, agropastoral land cover had decreased gradually to register at 45%. Scrubland showed the most significant increase to 53%. Forest cover also increased to 2% in 2018 (Figure 8c).

Scrubland, being the majority of land cover in Fariza in 1984 at 52%, barely altered throughout the temporal analysis, remaining in the low 50th percentile, still at 52% in 2018. The agropastoral class began at 40% in 1984 and registered a decrease to 34% in 2018. Forest land cover more than doubled between 1984 and 2018, from 6% to 13% (Figure 8d).



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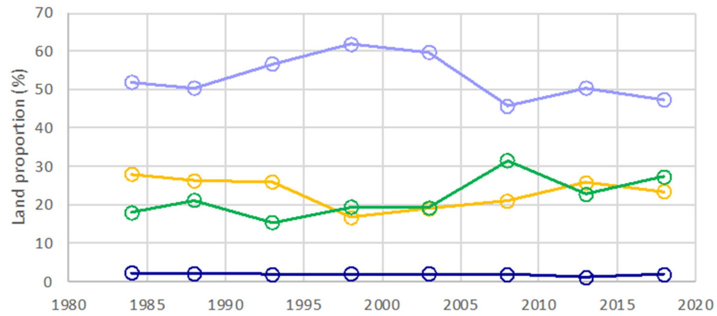

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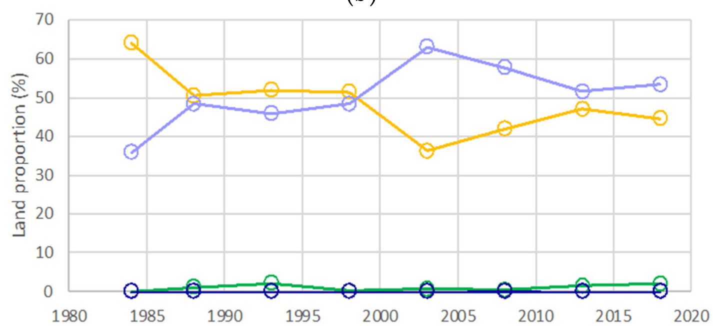

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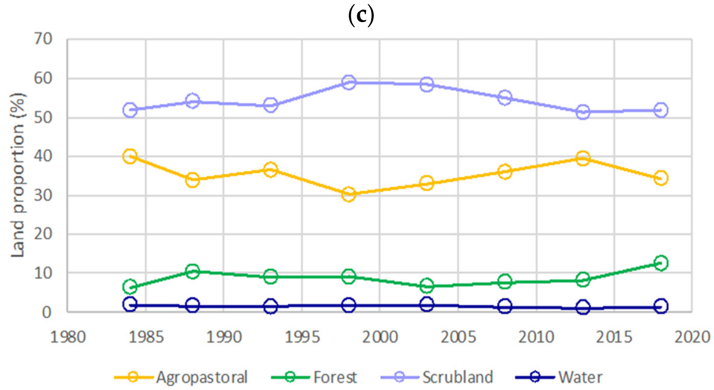


(**d**)

Figure 8. Percentage of land cover change in Spanish municipalities: (**a**) Pino del Oro, (**b**) Villardiegua de la Ribera, (**c**) Argañín, and (**d**) Fariza.

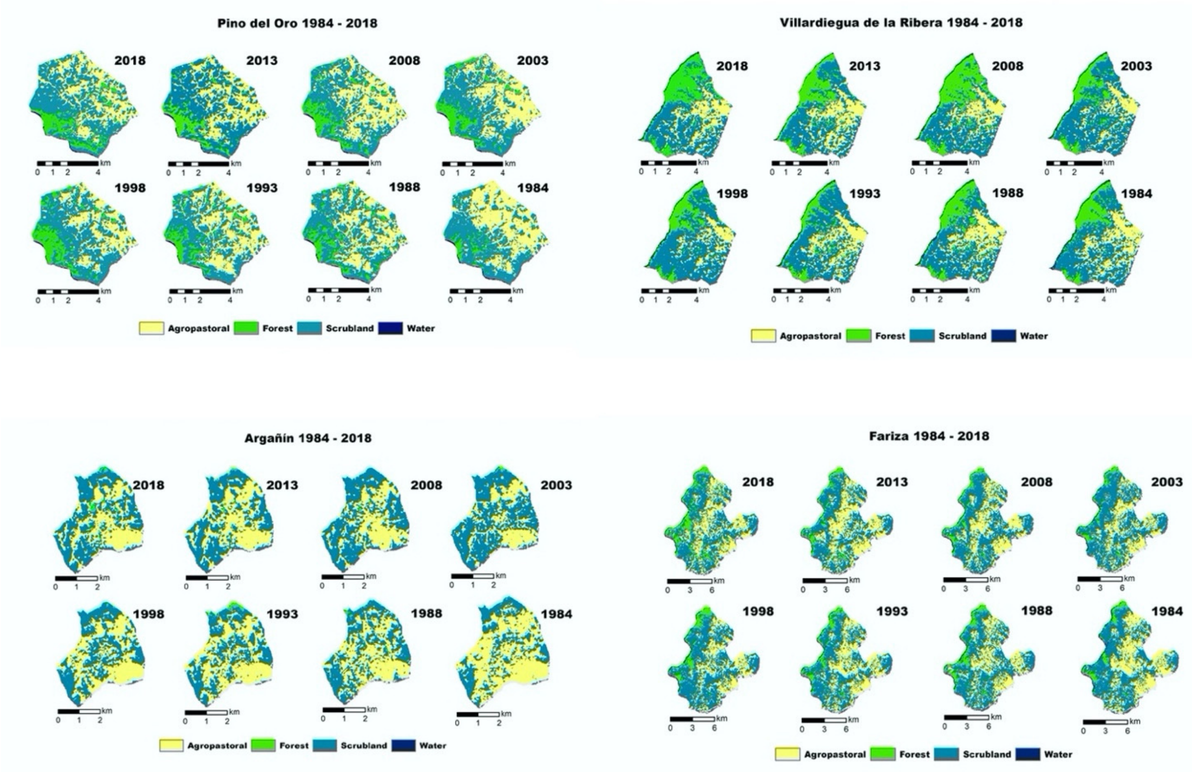
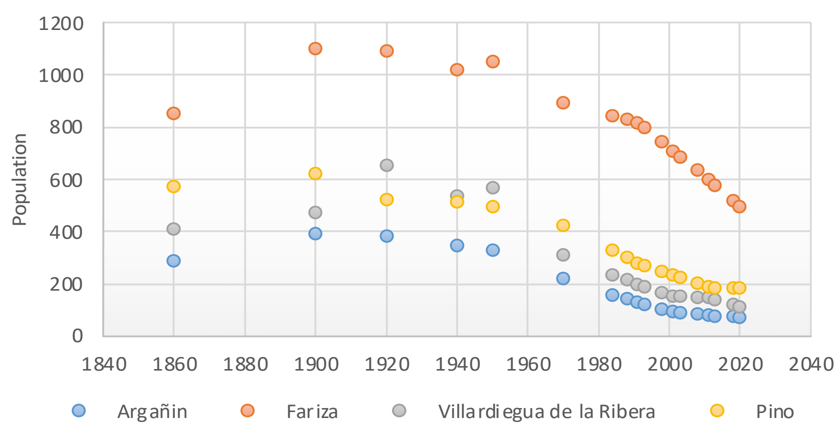


Figure 9. Temporal land cover change maps of Spanish Municipalities (1984–2018).

3.2.4. Population and Land Cover Class Correlation Analysis

With emigration from this region being a significant driver of landscape change, the Pearson coefficient was calculated among the three land cover vegetation classes (agropastoral, scrubland, and forest) in all eight municipalities and the available population data (Table 7). Since water was such an insignificant amount of land cover, it was not included in the correlation analysis. As Landsat scenes were captured in between years of official census recording, matching population years with Landsat scene years was achieved through the interpolation of both the Spanish and Portuguese population (Figure 10a,b). All municipalities, except for Miranda do Douro, followed predictable declines in population. Since the recent publication of 2020 census, however, Miranda do Douro has seen a slight decline in population [80].



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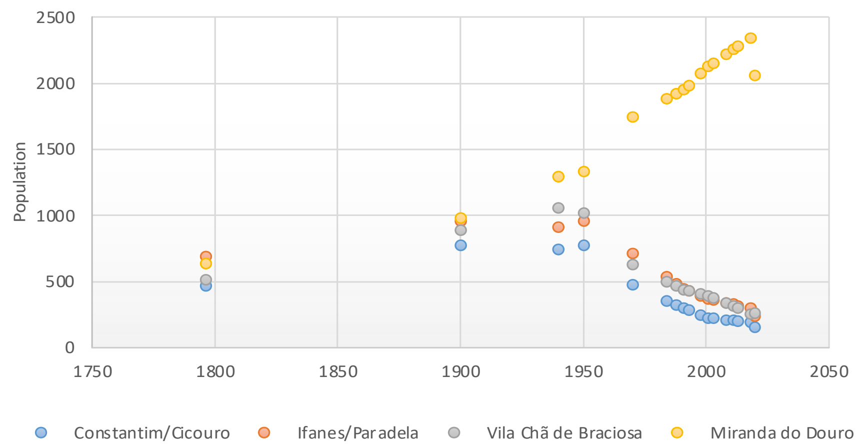

(**b**)

Figure 10. Population trends in study area by year: (**a**) Spanish and (**b**) Portuguese municipalities.

Forest land cover and population showed negative correlations with forest land cover increasing and population decreasing in six of the eight municipalities. A positive correlation of agropastoral land cover declining with population was most significant with three of the four Spanish municipalities.

Scrubland-population correlations varied between negative and positive among the municipalities. Most notable were the negative correlations in Pino del Oro and Argañín, indicating a decrease in population and an increase in scrubland. Ifanes-Paradela had a notable positive correlation with both decreasing population and scrubland (Table 7).

Table 7. Pearson coefficient (r) calculated for land cover classes and population trends in municipalities in study area.

	Constantim-Cicouro	Ifanes-Paradela	Miranda do Douro	Vila Chã de Braciosa	Pino del Oro	Villardiegua de la Ribera	Argañín	Fariza
Agropastoral-population	0.35	−0.20	0.41	0.04	**0.67**	**0.50**	**0.80**	0.02
Scrubland-population	0.47	**0.51**	−0.36	0,00	**−0.50**	0.15	**−0.78**	0.16
Forest-population	**−0.74**	**−0.56**	0.07	−0.03	**−0.58**	**−0.59**	−0.32	−0.36

4. Discussion

At the heart of this research are the effects of the gradual abandonment of the traditional agrosilvopastoral activities as a result of the socioeconomic factors that led residents to emigrate. Today, the remaining residents still engaged in agropastoralism maintain a tense relationship with government authorities tasked to manage the integrity of the natural parks and prevent wildfires. According to ethnographic sources, the region in the past had few wildfires. Today wildfires are considered to be one the greatest threats to ecological integrity in the Duero River borderlands region [36,81]. From interviews with residents who worked the landscape as agropastoralists from the 1970s and earlier, when asked to describe the landscape in the decades before the migration, the common response was "it was cleaner" in reference to the absence of so much overgrown vegetation and the prevalence of farming and grazing. [35].

4.1. Ethnographic Analysis

The common thread of the perception study was one of loss–loss of a traditional way of life as well as its socioeconomic and environmental effects on the landscape. Many interviewed struggled to find solutions to the problem of this loss through the development of tourism or a resurgence in the rural agropastoral economy, but felt hindered by the lack of public investment to increase tourism infrastructure and publicity. Additionally, returning to the original agropastoral economy was often viewed pessimistically and with disdain because it was perceived as very laborious, poorly compensated, and unattractive to younger generations. Although the region had been recognized for its environmental singularity with the declaration of the parklands, this distinction was now seen as more of a hindrance and viewed negatively by those few residents who maintained the traditional agrosilvopastoral use of the landscape. In all municipalities, residents expressed a concern with the new vegetative growth where there had once been farming and grazing. Public officials now fined and sometimes obstructed residents from using the land as before the creation of the protected zones. Fines are issued to residents who cut down, prune, or use controlled burns to remove certain species of trees on private land without prior approval. For many residents, this was viewed as an affront to their traditional land use. Despite the park and biosphere declaration, informants believed that the continued existence of their region, their traditions, and their way of life were in danger and would eventually disappear due to not only the loss of their population, but also public neglect, mismanagement, and the environmental impact of these decisions. These factors further exacerbated this perception of loss.

The perceptions of the Duero River borderland landscape from the stakeholders allowed for a more in-depth quantitative analysis, to demonstrate the impact of these human decisions on the landscape vegetation from the 1980s to the present.

4.2. Land Cover Change

The overall trend in the study area shows a significant increase in forests (from 10% to 22%), linked to a decrease in agropastoral lands (from 39% to 35%) and in scrubland (from 50% to 42%). At the municipal level there were some particularities, yet the loss of agropastoral lands and the increase in natural vegetation coincided with a steady rural abandonment process demonstrated by population statistics. The only exception was Miranda do Douro. It is the largest municipality in the area and was the only one with a population increase, where a loss of agropastoral land could not be perceived.

Although obtained land cover change trends are consistent in the long-term, short-term differences can be observed that might not be related to real changes in land cover but rather to classification issues [82]. For instance, in 1998, in some Portuguese municipalities the scrubland area was larger than the five-year period preceding or after it. These short-term changes need to be interpreted with care, since they might reflect particularities in the climatic conditions of that particular year, or other issues, which affected vegetation growth and made the separation of scrubland-agropastoral or scrubland-forest more difficult. In effect, 1998 was a particularly dry year with only 282 mm of rainfall recorded in the meteorological station of Zamora (40 km from the study area), which has a historical mean of 379 mm. Such anomalous years are challenging from the point of view of classification, since vegetation growth and dynamics might differ substantially from their normal pattern [83]. In addition, it must be considered that agropastoral lands in the area typically follow a rotation cycle with long fallow periods, where spontaneous vegetation might grow, enhancing the confusion with scrubland areas during fallow years. It is also important to consider that scrublands might have scattered Quercus trees and some tall shrubs, so the confusion with forests might also occur. Last, but not least, wildfires (a significant driver for land cover change) in the area during the study period might clearly impact classification results.

4.3. Drivers for Land Cover Change

Long-term land cover change and the current state of landscape vegetation are a result of not only demographic change in the Duero River borderlands region but also a consequence of an interplay of several drivers that include: agrosilvopastoral abandonment, government landscape management, and preservation policies, wildfires, and post-fire vegetation recovery (Table 8). All have had a significant impact since the mid-20th century. Increasing abandonment since the 1960s, followed by afforestation programs beginning in the 1990s and then natural park creation by the early 2000s, have all contributed to further vegetative growth. Moreover, policy decisions restricting past land use (cutting, burning, cultivation, pasturing) have also had an impact. The damage caused by wildfire has counteracted the growth somewhat, with an increase in fire events since 2000, but forest growth has nevertheless seen modest to significant increments in all municipalities and the greater study area.

Table 8. Drivers of landscape vegetation change since the 1960s.

Driver	Type	Time Period	Country	Effect
Emigration and migration	Social	1960s–present	Both	Gradual abandonment of agrosilvopastoral land and activities
Park and biosphere creation	Policy	Portugal: 1998 Spain: 2003 Biosphere: 2015	Both	Protected zones enforce preservation policies that control and limit past landscape agrosilvopastoral use for remaining residents
Wildfire events (larger and more frequent)	Natural or human provoked	2000s to present	Both	Loss of hundreds of hectares of forest and scrubland. Inter-year vegetation recovery
Afforestation programs	Policy	1990s to present	Portugal	Increase in hectares of forest cover class
Public watershed management lands (MUPs)	Policy	Late 19th C–present	Spain	Led to an increase in both scrubland and forest growth in areas not burned in wildfires

4.3.1. Emigration and Migration

Ethnographic data have fueled the idea of change on this borderland landscape's history. Emigration resulting in agropastoral lifestyle abandonment and the transformation of vegetation land cover have been the primary indicators of change for the long-term residents in the area. In the study area, the effects of this abandonment are most pronounced in Spain. Agropastoral land cover declined moderately to highly in three out of four of the Spanish case study municipalities. The Portuguese case studies, although demonstrating small losses in agropastoral land cover, did not reach the significant levels found in Spain. Portuguese demographic data for the greater Miranda do Douro county (which includes all of the Portuguese municipalities covered in this study) from the agricultural census confirms these findings with a detectable rise in small scale agriculture from 21,470 hectares of agricultural land utilized in 2001 to the next available data of 21,813 hectares in 2011 [84]. Although not a significant increase, the amount of people still maintaining agropastoralism has ameliorated, to a small degree, the effects of population decline from migration and emigration. A social diagnostic report from the Miranda do Douro county authorities, however, projects this increase as unsustainable due to the fact the average age of agricultural workers at the time of the last agricultural census was 64 years old [84]. Important to note as well is that, unlike in Spain, which has experienced a population decline in all municipalities in this study, the municipality of Miranda do Douro has trended upwards in population growth. Recent census data, however, show a decline in population [80].

4.3.2. Government Policies–Park and Biosphere Zones Effects on Residents

Forest land cover increased in all the case study municipalities in the study between 1984 and 2018. Within the greater study area there was a nearly 12% increase from 1984. Human policy decisions between the two nations have played a role in this increment. Most notable are the creation of the international natural park zone followed by the UNESCO-designated biosphere reserve. With the objective of protecting the singularity of the natural ecosystem, new restrictions and monitoring have been placed on past agrosilvopastoral land use, instead favoring forest growth and a more preservation-style management. Although compliant and largely in agreement with the new landscape management laws, particularly those aimed at preventing wildfires, residents indicated that past landscape agrosilvopastoral management before the mass migration allowed for more biodiversity of plants and animals [35,85]. According to residents, this previous type of land management also controlled fires, due to more people living on and cultivating/pasturing the landscape thus reducing what they perceived as the overgrowth of vegetation.

4.3.3. Wildfires

Wildfire has had a significant impact on the landscape, its people, and even policy. Offsetting forest growth to an extent has been the occurrence of wildfires in recent years. This factor is typical of other findings in Spain near protected areas [86]. In Portugal, the data from the county report of areas at risk of wildfire and specially prepared GIS data from the Castile and Leon government's Territory and Environment division have provided information detailing the location, date, and extent of wildfire (Figure 11) [87]. From Figure 11, wildfires, since 2000, have been more extensive and damaging on the Spanish side of the border. From Table 6, forest cover, despite its overall increase from 1984 to 2018, dropped 2.38% between 2008 and 2013 (years in which there were significant wildfire events). Scrubland (Table 6) registered notable drops of 4.16% between 2003 and 2008 and 4.75% between 2013 and 2018, which were years of significant wildfires (Figure 11). Even before GIS data were available, in the period from 1984 to 1988, the province of Zamora registered a total of 61,130.6 hectares burned [88]. NBR data in the neighboring municipalities of Fariza and Argañín dropped significantly to register negatively for 1988, indicating a fire in the area (see supplementary data, Table S1 and Figure S3). In Pino del Oro in 2015 and in 2017, wildfires caused massive damage with NBR in 2018 showing a significant decrease from the previous year (see supplementary data, Figure S3).

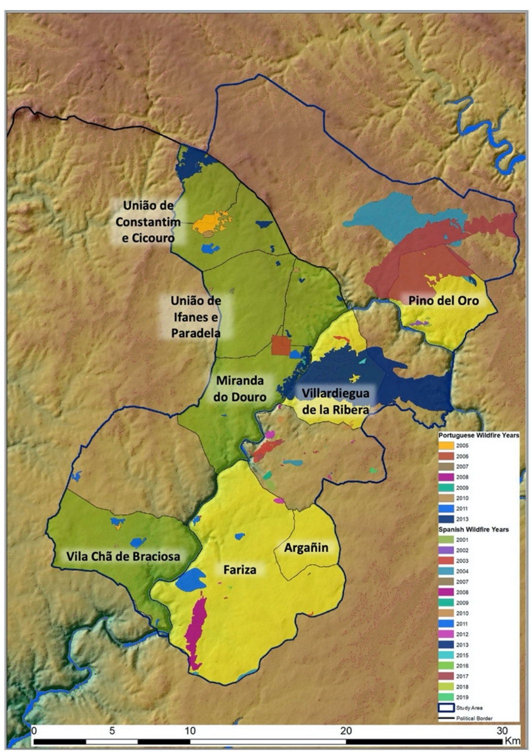

Figure 11. Portuguese municipalities (green) and Spanish (yellow) wildfire burn areas.

Another important factor with wildfire is the regeneration of the vegetation biomass post fire. Long an important element of the landscape, whether occurring naturally or provoked, fire has been viewed by many residents in the region until more recent decades as a natural phenomenon. With rural abandonment however, shrubland and pasture lands have seen excessive regrowth with taller, more extensive grasses and shrubs [89] resulting in more "homogenization" and fuel for future, more frequent, and intense wildfires [90–92].

4.3.4. Afforestation Programs-Portugal

Despite the recurrent wildfire occurring both before and since the natural park and biosphere declarations, there have been national rural land management strategies in both nations aimed at afforestation and watershed management. On the Portuguese side of the border, governmental policies regarding land use differed from Spain, with Portugal implementing afforestation programs for both environmental and economic benefit. Two programs had a significant impact on forest growth in Portugal: the European Economic Community Initiatives (EEC, No 2080/92, https://op.europa.eu/s/oJB2) [accessed on 16 February 2021] in the 1990s and RURIS, the joint EU and Portuguese government forestation program (https://www.ifap.pt/fta-ruris-regras) [accessed on 16 February 2021], in the early 2000s [93]. Mostly detectable in the Ifanes-Paradela and Constantim-Cicouro municipalities, these programs contributed to an increase in forested areas in the study area.

4.3.5. Historic Public Watershed Management

On the Spanish side of the border, afforestation, although present in the province of Zamora, did not occur in the case study municipalities. Reforestation has occurred in Spain and more specifically Zamora, under the same initiative in the 1990s as in Portugal under the EEC 2080/92 and later in the diverse rural development program called *Fondo Europeo Agrícola de Desarrollo Rural* (FEADER) http://www.redruralnacional.es/fondo-europeo-agrario-de-desarrollo-rural-feader-. In areas where rural lands were within the parameters and jurisdiction of a natural park (as in the case of all of the Spanish municipalities in this study being within the Arribes del Duero Natural Park) reforestation was curtailed according the norms established by the Red Natura 2000 network of natural preserves in the European Union [94]. Instead, long term land management policies positively affected another land cover class, scrubland. In Spain, a public land watershed management system called Montes de Utilidad Pública (MUP) was initiated by the national government and maintained by the regional and provincial governments [95]. In some Spanish municipalities, large swaths of land fall under this administration and protection (Figure 12). In the study area, within these protected areas, rough grazing is permitted but cultivation is not. Scrubland predominates and is maintained in these publicly managed areas, but with rural abandonment and less pastoralism some of these areas have seen more arboreal growth. In Argañín, a municipality with MUP lands, there was a detectable rise in scrubland from 1984 to 2018, as found in other studies. In addition, there was a minor increase in forest cover at the expense of a decline in agropastoral land [96]. Fariza, also with significant lands under MUP jurisdiction, mirrored Argañín's statistics, but they were less pronounced: a 6% increase in forest land cover and scrubland registering a very minor increase.

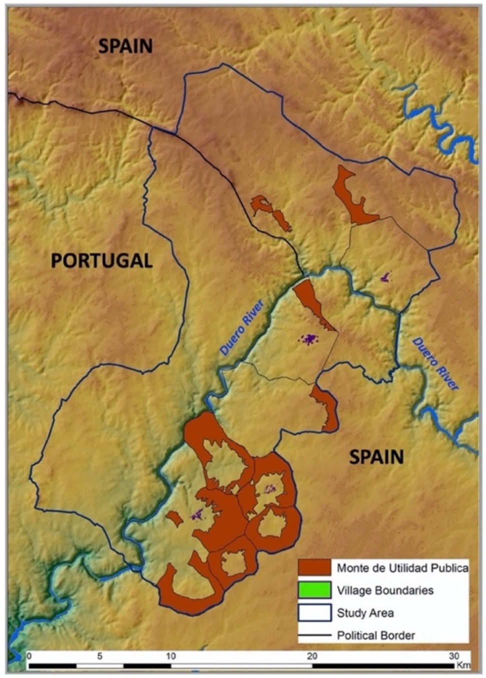

Figure 12. Public watershed management areas (MUPs) in the Spanish part of the study area.

5. Conclusions

In the Duero River borderland region beginning with the protohistoric and Roman periods to the mid-20th century, the population has waxed and waned throughout the centuries. One factor though that has been consistent throughout: land cover has been influenced by the prevalence of agrosilvopastoralism. Since the mid-20th century, a new story is being told: a story of population decline, of rural abandonment, and of changing perceptions of this landscape from stakeholders who now value the landscape less for its traditional land use but instead for its ecological singularity and, to a lesser degree, the socioeconomic benefits that can be reaped from this ecological distinction and its evolving land cover.

In this study, we have applied an effective integrated methodological approach to interpreting the reasons for temporal land cover change. After implementing an initial time series of vegetation indices for the region, we developed a quantifiably accurate and effective landscape classification with stable training sites, which was used to demonstrate diachronic land cover change over a 34-year period. Combined with both ethnographic testimony and analysis of demographic statistical data, this integrated approach has furthered our understanding of the causes and has provided nuance to temporal landscape change, by adding a more "bottom up" approach that cannot be fully understood by only looking down from space.

Not a monolithic region of identical characteristics, the analysis demonstrated gradations of land cover changes when conducting a transborder analysis. It highlighted the national and historical differences in land management governmental policies and demographic change. Spanish land abandonment was the greatest in the region, and our land cover change findings complement current national and European demographic studies. Throughout the international borderland study area, however, both qualitative and quantitative data illustrated that forest land cover has increased since 1984 because of not only agrosilvopastoral abandonment, but also other policy drivers aimed at afforestation and forest preservation, with the creation of protected natural areas as well. Due to increased forest cover throughout the region, and in some municipalities cases of increased scrubland, wildfire has been and will continue to be an ever-present threat, particularly in the excessively hot and vegetation-drying summer months.

Applying Wu's definition of landscape sustainability to this region [20], our results demonstrate that the landscape is less sustainable today than it was under the more agrosilvopastoral type of management common until the ongoing, gradual population decline that began in the 1960s.

Looking to the future of this borderland landscape, Portugal and Spain are coupled with a two-pronged concern: (1) How to manage the landscape and its land cover once its population dedicated to agropastoralism (particularly in the case of Portugal) retires. Spain, already having lost much of its agropastoralism, is a nearby signpost for what lies ahead for Portugal. (2) How to effectively manage its park resources in a sustainable manner to maintain biodiversity and economic development, as well as to avoid ecological and economic loss because of wildfire. As ecosystem services continue to change in the region from one less dependent on agropastoralism to one dominated by cultural tourism and ecotourism, future research such as this one, which assess the impacts of these changing dynamics, will be essential for the long-term sustainable development of the landscape.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/su132413962/s1, List S1: List of aerial photography consulted, Table S1: Vegetation indices for greater study area, Figure S1: Normalized Difference Vegetation Index (NDVI) calculated for study area municipalities (1984–2018, Figure S2: Bare Soil Index (BSI) calculated for study area municipalities (1984–2018), Figure S3: Normalized Burn Ratio (NBR) calculated for study area municipalities (1984–2018).

Author Contributions: Conceptualization, K.P.H. and J.Á.-M.; methodology, K.P.H. and J.Á.-M.; software, K.P.H. and J.Á.-M.; formal analysis, K.P.H. and J.Á.-M.; investigation, K.P.H. and J.Á.-M.; writing—original draft preparation, K.P.H. and J.Á.-M.; writing—review and editing, K.P.H. and J.Á.-M.; visualization, K.P.H. and J.Á.-M. All authors have read and agreed to the published version of the manuscript.

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